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EVALUATION OF ENVIRONMENTALLY AGED POLYMER/COMPOSITE MATERIAL BY ULTRASONIC INSPECTION

ROBERT F. ANASTASI
MATERIALS TESTING AND EVALUATION BRANCH

March 1991

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ABSTRACT

Ultrasonic nondestructive evaluation (NDE) techniques were used to examine glass-fiber reinforced polymer matrix material that had been exposed to accelerated environmental aging (weathering). General results showed that the weathered specimens severely attenuated the ultrasonic energy and that the extent of the attenuation corresponded to the degree of weathering.

INTRODUCTION

Ultrasonic nondestructive evaluation (NDE) techniques are being explored for application in monitoring the deterioration of glass-fiber reinforced polymer matrix composite materials. Conventional ultrasonic equipment and testing arrangements were used that consisted of transducer, materials sample, and coupling medium (gel for contact and water for immersion methods). The sound generated by the transducer propagates through the coupling, into the sample, and is reflected from acoustic interfaces (flaws, material discontinuities, and sample surfaces). These reflections are either received by another transducer using a through-transmission technique or by the sending transducer using a pulse-echo technique. A typical A-scan signal (time versus voltage display) consists of an initial pulse (main bang), a front surface echo (in water immersion method), and a series of back surface echoes of decreasing amplitude.

The time between two successive back echoes is the time it takes the sound to travel through the material twice. This echo time separation can then be used to calculate either material thickness given material acoustic velocity, or the acoustic velocity given the material thickness. The relationship is given as:

$$V = (2\,d)/t \qquad (1)$$

where V is the acoustic velocity in the material, d is the thickness, and t is the time between successive back echoes.

The signal amplitude (amount of sound energy reflected from acoustic interfaces) can be used to estimate flaw size when related to calibration standards. A material's condition can also be inferred when signals from good and bad samples are compared. Additional details of ultrasonic inspection methods can be found in References 1 through 3.

This report describes initial studies in applying ultrasonic inspection methods to detect changes in aged polymer composite samples. The approach was to subject a set of specimens to ultrasonic inspection by contact and water immersion methods using various frequency transducers. The resulting A-scan signals were examined for echo content and amplitude and then correlated with specimen environmental exposure time.

TEST SPECIMENS

The three test specimens examined in this study were machined from a unidirectional S2 glass six-ply epoxy resin composite material. One specimen was not exposed to accelerated environmental aging and was used as a control, while the other two specimens were aged by immersion in water at 80°C (weathered) and subsequently dried in a vacuum oven. One specimen was aged for 144 hours and the other for 216 hours. As a result of this simulated weathering process, the specimens increased in thickness and the surface texture became rougher and appeared more pitted. Specimen identification (ID), thickness, density, and hours weathered (aged) for the three test specimens are given in Table 1.

1. KRAUTKRAMER, J., and KRAUTKRAMER, H. *Ultrasonic Testing of Materials*. Published by Springer-Verlag, New York, NY, 1983.
2. McGONNAGLE, W. J. *Nondestructive Testing*. 2nd Edition, Gordon and Breach, Science Publishers, Inc., New York, NY, 1969.
3. *Nondestructive Testing - Ultrasonics*. Classroom Training Handbook, CT-6-4, 2nd Edition, General Dynamics Convair Division, New York, NY, 1981.

Table 1. SPECIMEN PARAMETERS; IDENTIFICATION NUMBER, THICKNESS, DENSITY, AND HOURS WEATHERED

Specimen ID	Thickness (in.)	Thickness (mm)	Density (g/cc)	Hrs Weathered
S335	0.058	1.47	1.973	0
S3319	0.060	1.52	1.876	144
S3329	0.065	1.65	1.764	216

EXPERIMENTAL APPARATUS/TESTING

The experimental arrangement for both contact and water immersion method A-scans are schematically shown in Figure 1. A pulser/receiver, Panametrics Model 5052PRX, was used to send and receive ultrasonic signals to and from various transducers. The A-scan signals received were recorded and displayed on a digital data acquisition system, Data Precisions Data 6000. For each signal, 512 data points were recorded at a period of 10 nanoseconds (or frequency of 100 MHz). The recorded A-scans could be plotted on a Hewlett Packerd Plotter or transferred to a personal computer for signal processing, display, or hard copy.

A C-scan of the specimens was performed in a water immersion tank, Testech Model mis-100, using a pulser/receiver, Sonic Reflectoscope Model QC2000, that were coupled to a personal computer running scanning software developed in-house. A schematic of the video signal (a rectified A-scan signal) and the resulting color-coded output (C-scan) are shown in Figure 2. The maximum signal amplitude under the gate is converted to a color-code and plotted on the computer monitor. The color-code of high dB gain represents a sample with no apparent defects while low dB gain represents a sample with defects and voids.

The general test procedure for the A-scan starts by connecting the transducer to the pulser/receiver and coupling it to the test specimen using a gel for the contact method or water in the immersion method. The A-scans are monitored on the data acquisition systems while the pulser/receiver controls (energy, damping, and attenuation) are adjusted to optimize the signal to noise ratio. Signals for each specimen and transducer frequency can then be stored for later plotting and comparison.

The C-scan test procedure is similar to the A-scan procedure except the signals are processed via the tank, reflectoscope, and software to produce a two-dimensional color-coded image of the specimen.

In addition to A-scan signals of the specimens, a transducer response signal may be recorded. This is done by coupling the transducer to a block of homogeneous material (Plexiglas) and recording the resulting A-scan signal. Although not used in this study, this time domain signal can be used to characterize the transducer through spectral analysis to obtain center frequency and band width. These characteristics could be monitored to insure testing repeatability if a transducer was to be used for long periods.

RESULTS

General results for both the A-scans and C-scans show that the weathered specimens severely attenuate the ultrasonic energy, and that the extent of attenuation corresponds to the degree of weathering.

A-SCANS

In the contact pulse-echo technique, various frequency and diameter longitudinal wave transducers and a shear wave transducer were used to inspect the specimens. A series of A-scans for various diameter and frequency longitudinal wave transducers are shown in Figures 2 through 5. A-scans using a shear wave transducer are shown in Figure 6. In each figure the transducer response and signals for the three specimens are shown. The main bang and back surface echoes can clearly be seen in the unweathered specimen, ID S335. In the weathered specimens, ID S3319 and ID S3329, the main bang can be seen clearly while the back echoes are highly attenuated. The lower frequency transducer gives the best result even though back echoes are barely distinguishable in the weathered specimens. This signal attenuation as a function of frequency is illustrated in Figure 7 where A-scan signals of specimen ID S335 for different transducer frequencies are shown.

The contact through-transmission technique was demonstrated for a pair of longitudinal wave transducers of 5 MHz frequency. A series of A-scans in Figure 8 show signals for the three specimens. Again, the signal becomes highly attenuated as a function of weathering.

In the water immersion method, pulse-echo techniques were used to record A-scan signals for each of the specimens and the transducer response. As in the contact method, various transducers (diameter and frequency) were used to inspect the specimens. Figures 9 through 12 show the transducer response and signals for each of the specimens. The front surface and back surface echoes can clearly be seen in the unweathered specimen, while back surface echoes become attenuated in the weathered specimens. A-scan signals of the unweathered specimen ID S335 are shown in Figure 13 as a function of transducer frequency. The signal amplitude becomes severely attenuated for increasing frequency.

As in the contact method, results of the water immersion method show larger amplitude echoes for a lower frequency transducer. Also, the echoes from transducers of diameters 0.25" and 0.50" are similar in amplitude.

C-SCANS

Attenuation scans of the three specimens were performed using a 5 MHz/0.5" transducer with the reflectoscope gate located over the first back surface echo. Due to the severe attenuation in the weathered specimens, the receiver gain setting on the sonic reflectoscope was increased from 28 dB for the unweathered specimen ID S335 to 35 dB and 40 dB on the weathered specimens ID S3319 and ID S3329. The resulting color-coded images of the unweathered specimen and weathered specimens are shown in Figures 14 through 16, respectively. The relatively uniform color of the C-scan in Figure 14 indicates a solid specimen while the nonuniform pattern in Figures 15 and 16 indicate a specimen with discontinuities or areas of sound attenuation scattered throughout the specimen.

CONCLUSIONS

The composite specimens exhibited unique ultrasonic signatures which correspond to the degree of weathering. The unweathered specimen showed the best echo response while weathered specimens showed severely attenuated back surface echo signals. However, the attenuation effect of the weathered specimens was less severe at lower transducer frequencies than at higher frequencies. This is mainly due to better penetration capabilities of ultrasonic waves at lower frequencies (longer wavelength).

Contact and water immersion A-scan methods were both demonstrated with no apparent advantage of one method over the other. Both point measurement methods can be used to examine the echo amplitude of aged specimens. Although the C-scan method gave a pictorial representation of the aging effect, it was more time consuming than the A-scan method.

This report shows that ultrasonic inspection methods can detect changes in aged polymer composite samples. Recommendations for continuation of this study include examination of other polymer composite materials and more detailed studies relating changes in ultrasonic signal attenuation to change in the physical and mechanical properties of environmentally aged polymer composites.

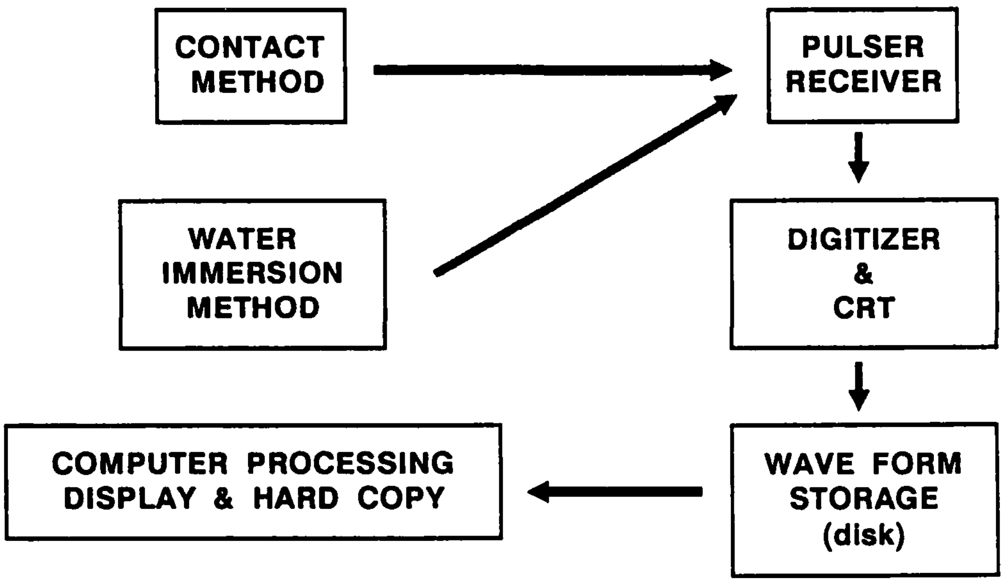

Figure 1. Block diagram of experimental test setup.

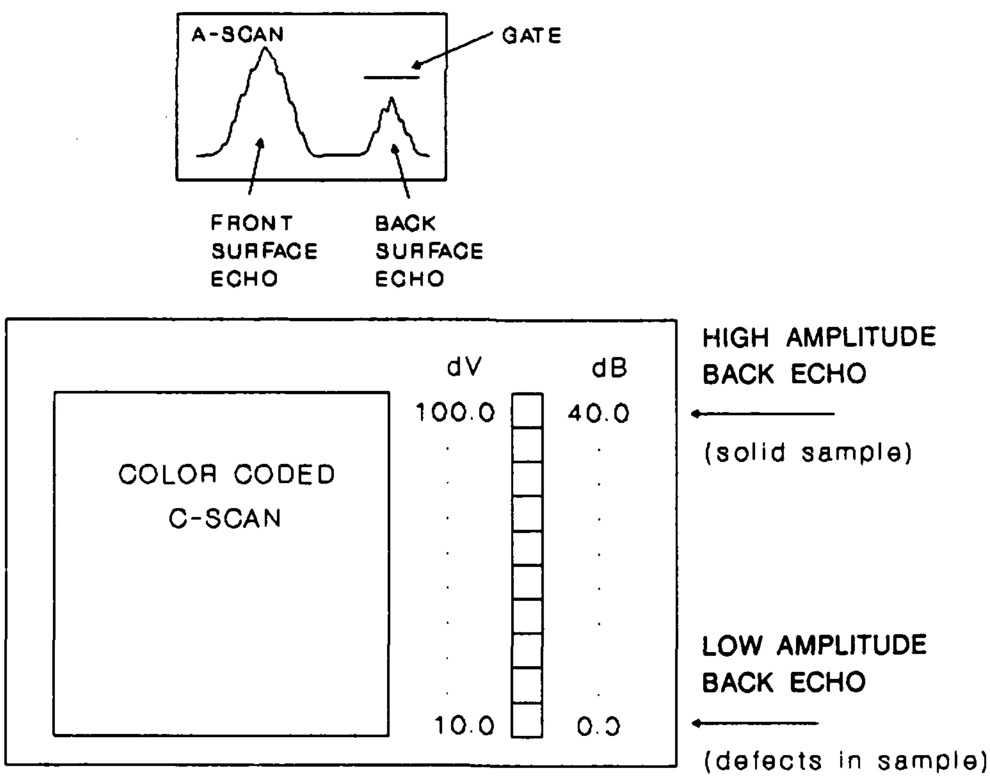

Figure 2. Diagram of video signal and color-coded C-scan.

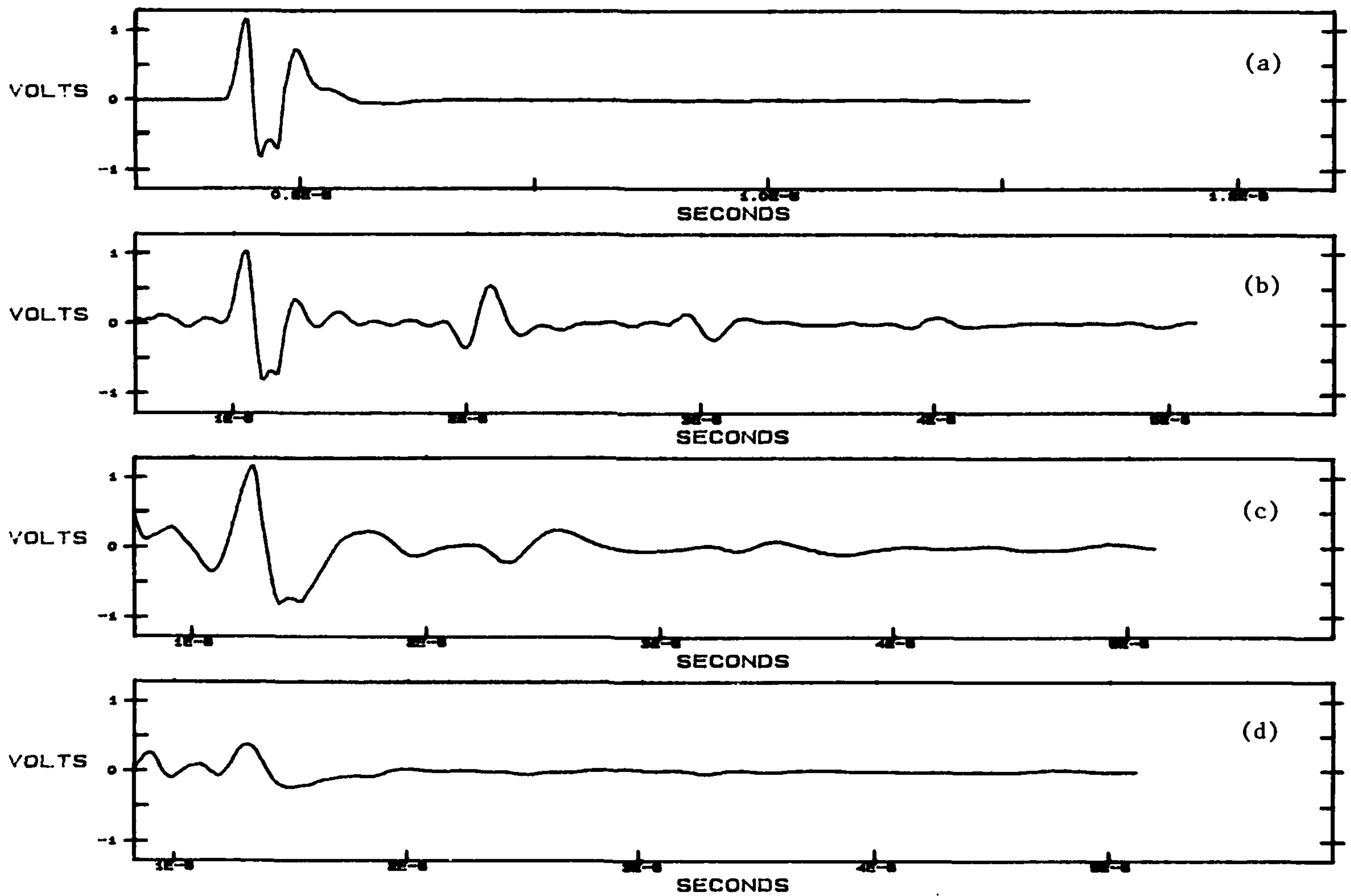

Figure 3. A-scans for contact method, 5 MHz/0.5" longitudinal wave; a) transducer response, b) specimen ID S335, c) specimen ID S3319, and d) specimen ID S3329.

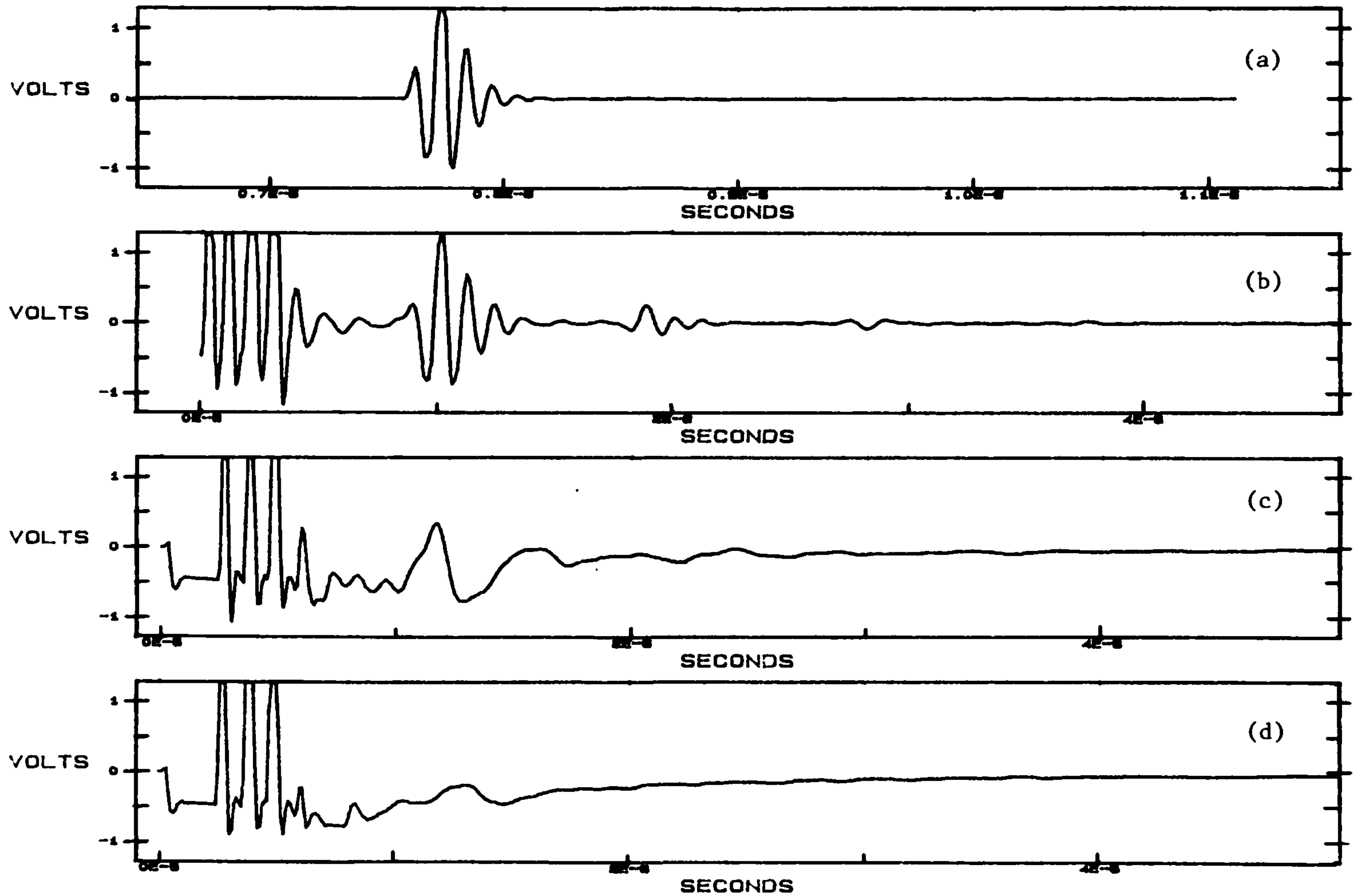

Figure 4. A-scans for contact method, 10 MHz/0.5" longitudinal wave; a) transducer response, b) specimen ID S335, c) specimen ID S3319, and d) specimen ID S3329.

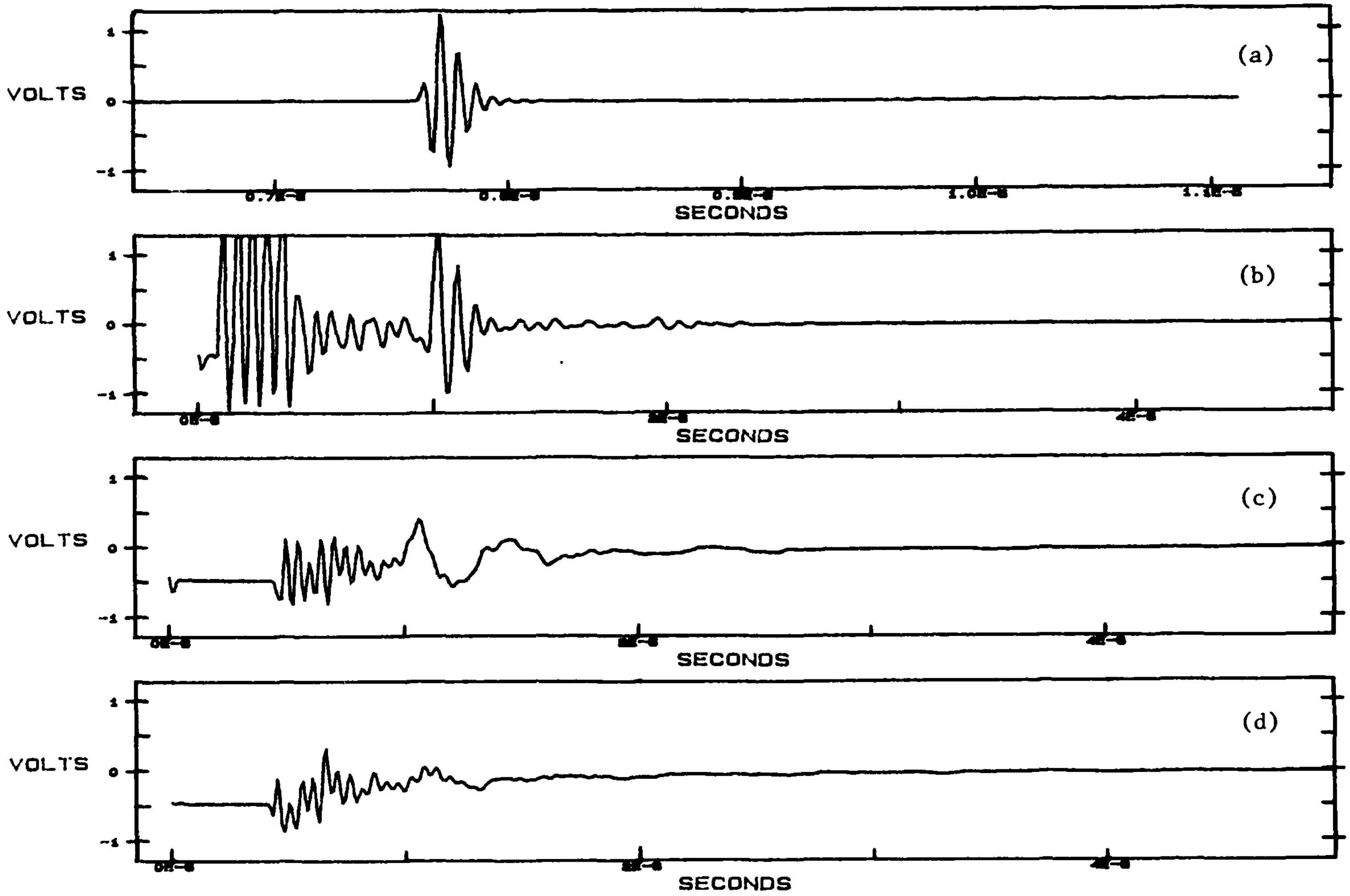

Figure 5. A-scans for contact method, 15 MHz/0.5" longitudinal wave; a) transducer response, b) specimen ID S335, c) specimen ID S3319, and d) specimen ID S3329.

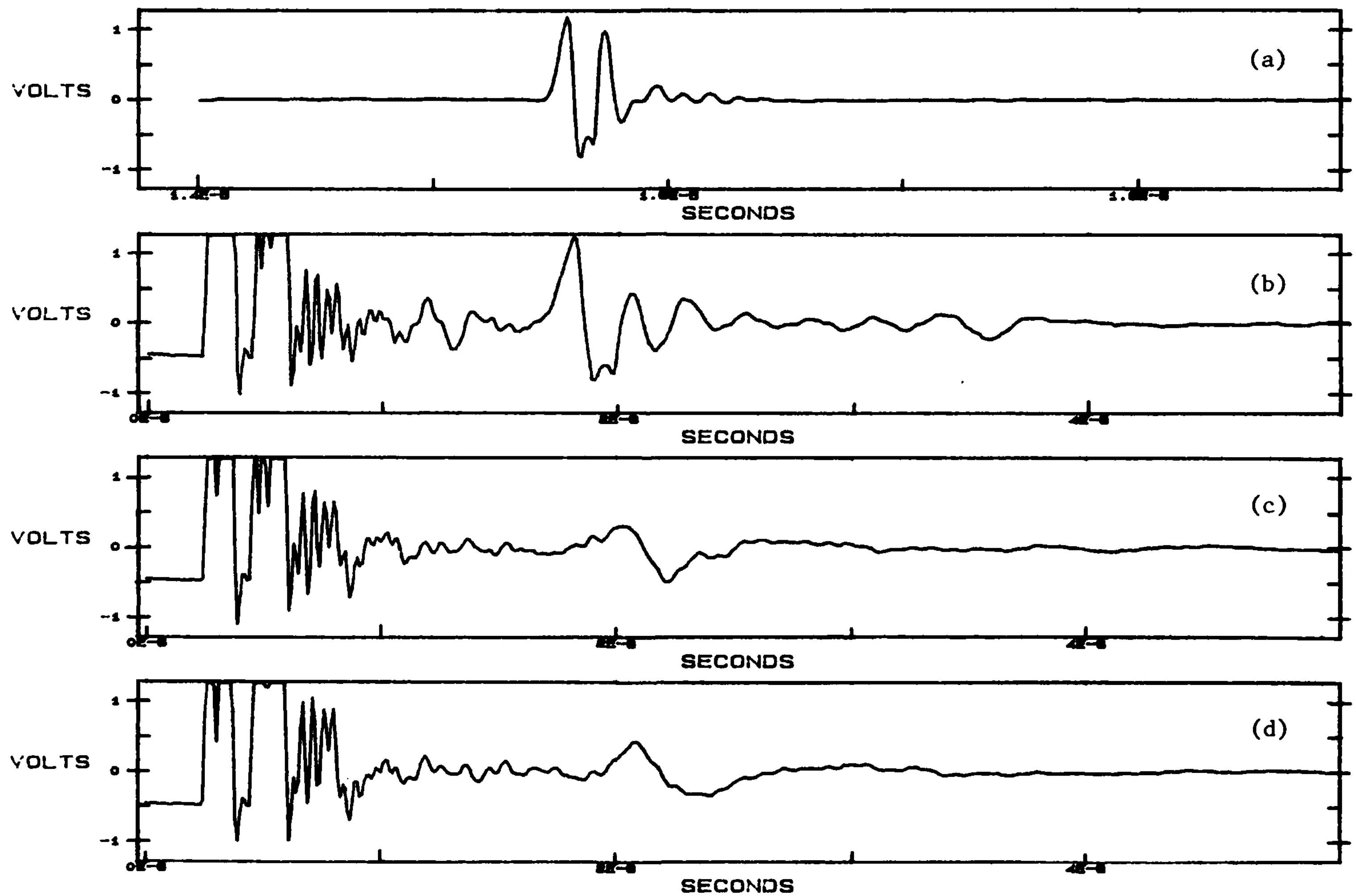

Figure 6. A-scans for contact method, 5 MHz/0.5" shear wave; a) transducer response, b) specimen ID S335, c) specimen ID S3319, and d) specimen ID S3329.

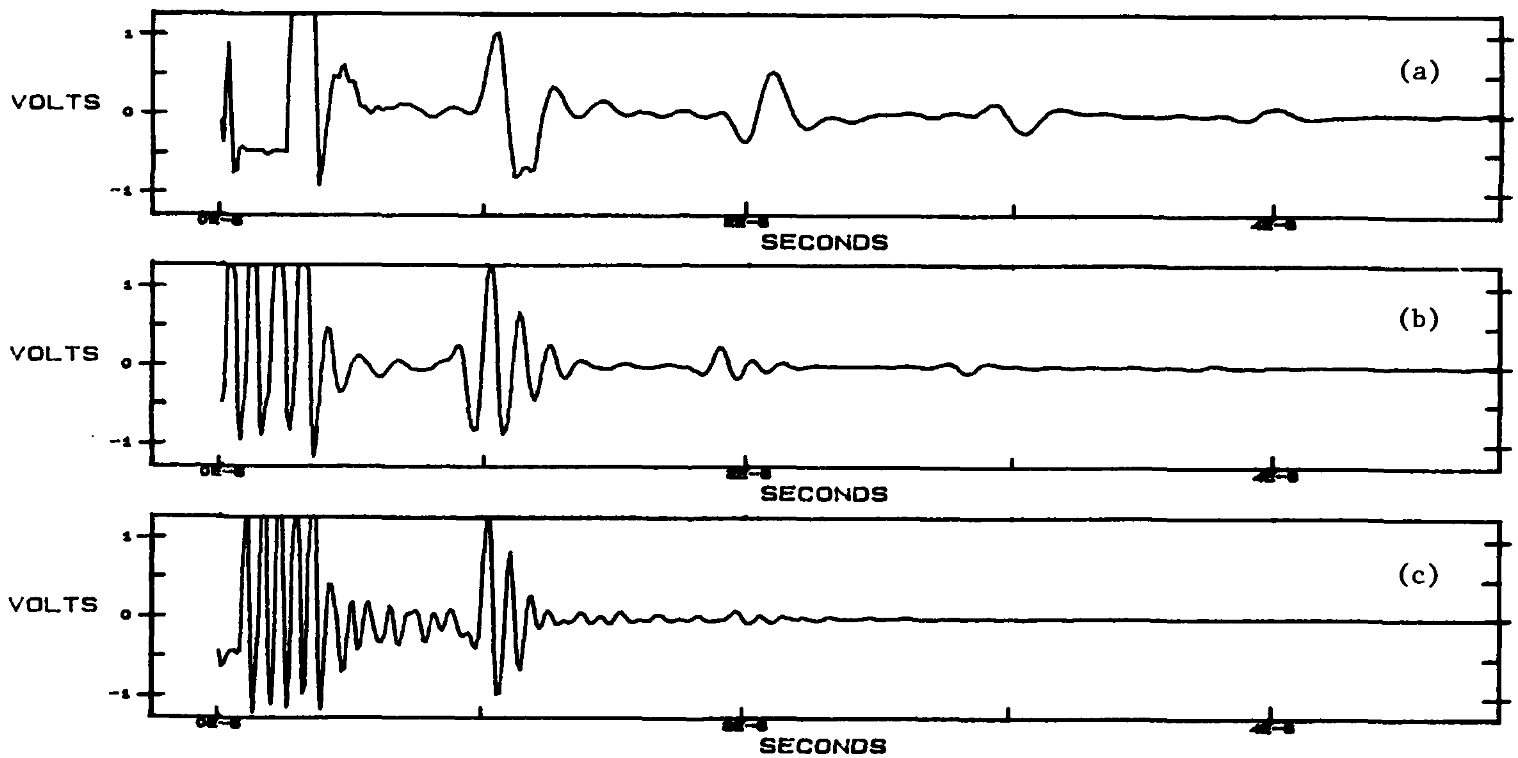

Figure 7. A-scans of specimen ID S335 versus transducer frequency using contact method; a) 5 MHz/0.5", b) 10 MHz/0.5", and c) 15 MHz/0.25".

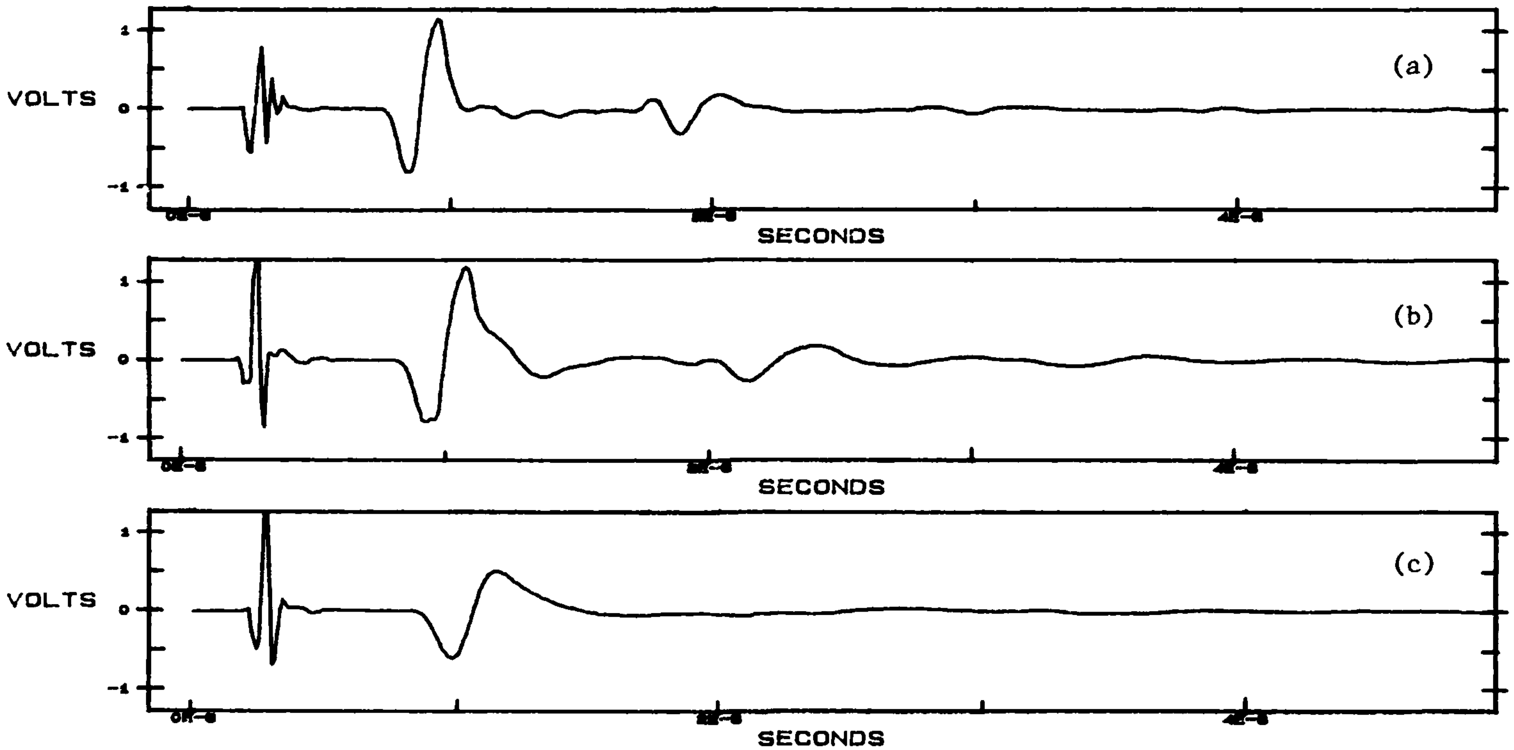

Figure 8. A-scans for contact method through-transmission, 5 MHz/0.5" longitudinal wave; a) specimen ID S335, b) specimen ID S3319, and c) specimen ID S3329.

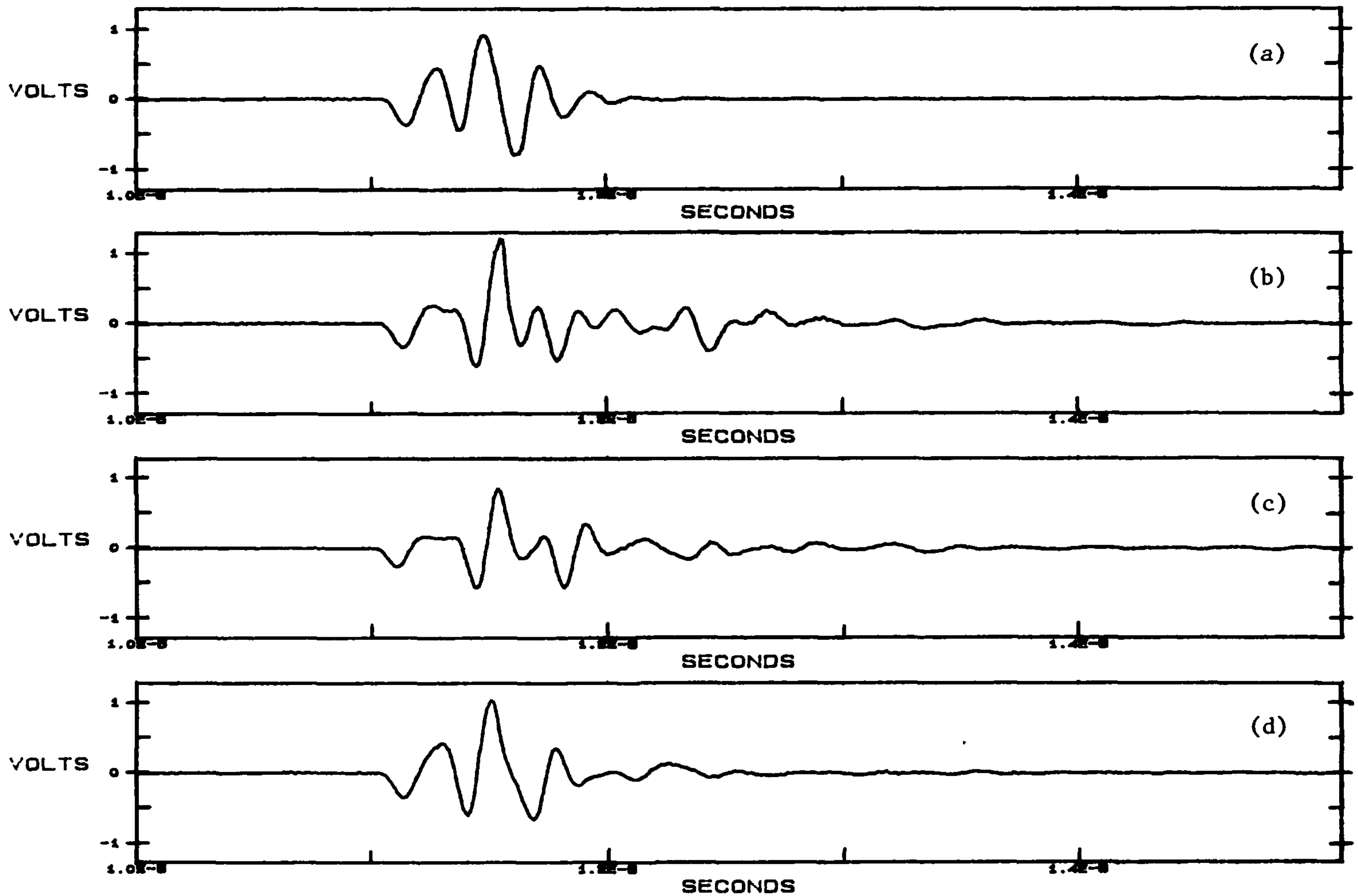

Figure 9. A-scans for water immersion method, 5 MHz/0.5"; a) transducer response, b) specimen ID S335, c) specimen ID S3319, and d) specimen ID S3329.

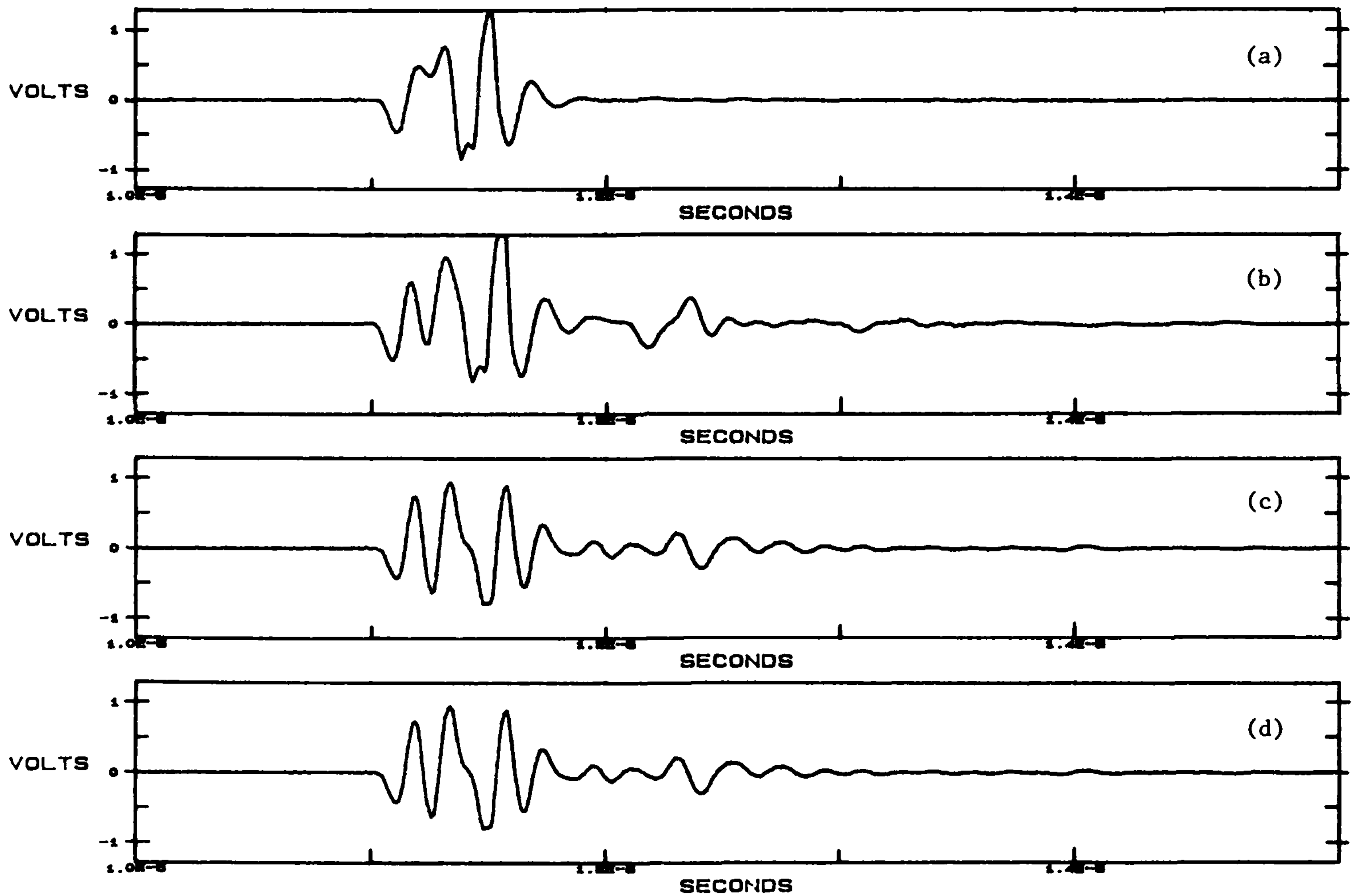

Figure 10. A-scans for water immersion method, 5 MHz/0.25"; a) transducer response, b) specimen ID S335, c) specimen ID S3319, and d) specimen ID S3329.

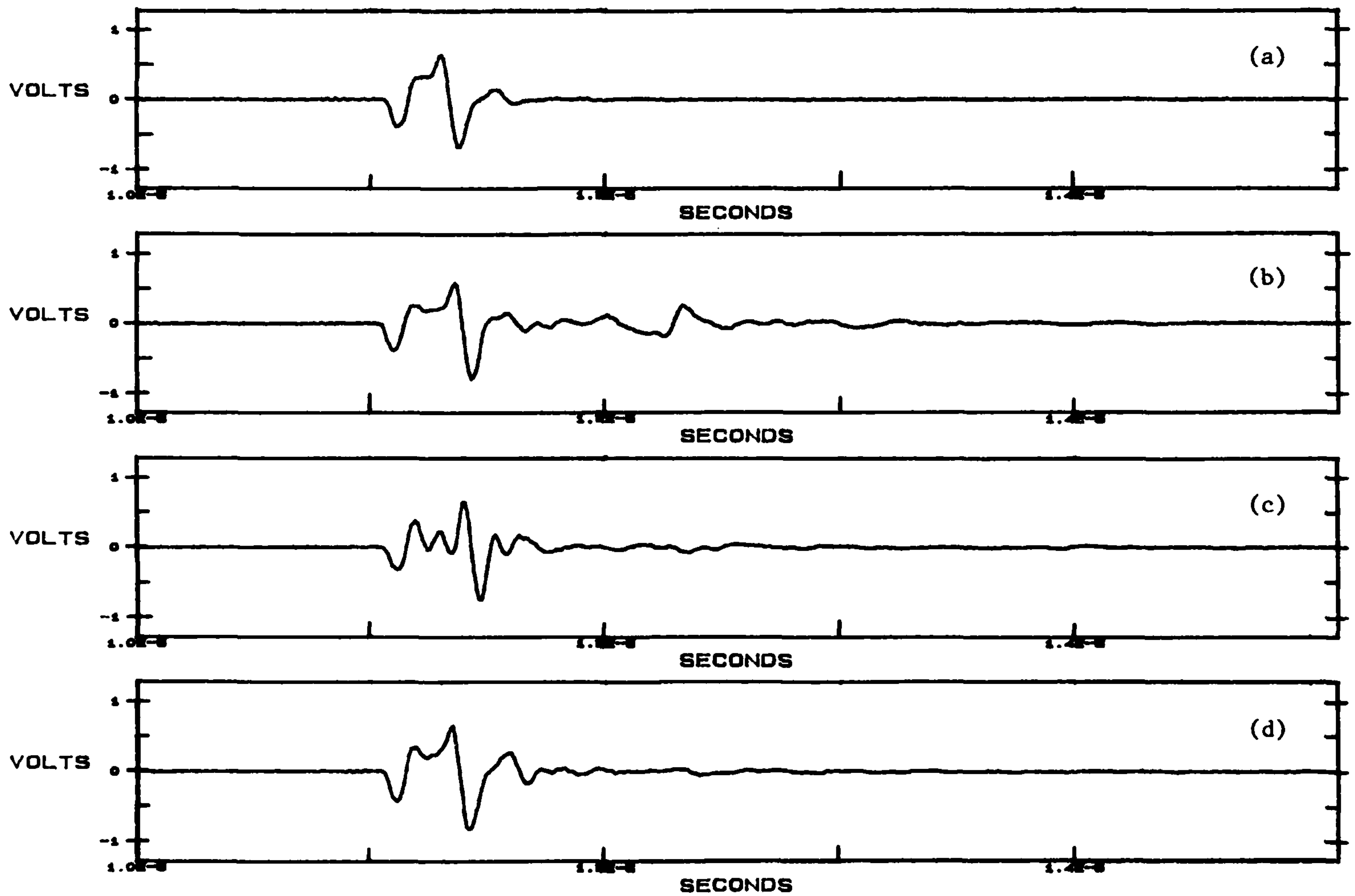

Figure 11. A-scans for water immersion method, 10 MHz/0.25"; a) transducer response, b) specimen ID S335, c) specimen ID S3319, and d) specimen ID S3329.

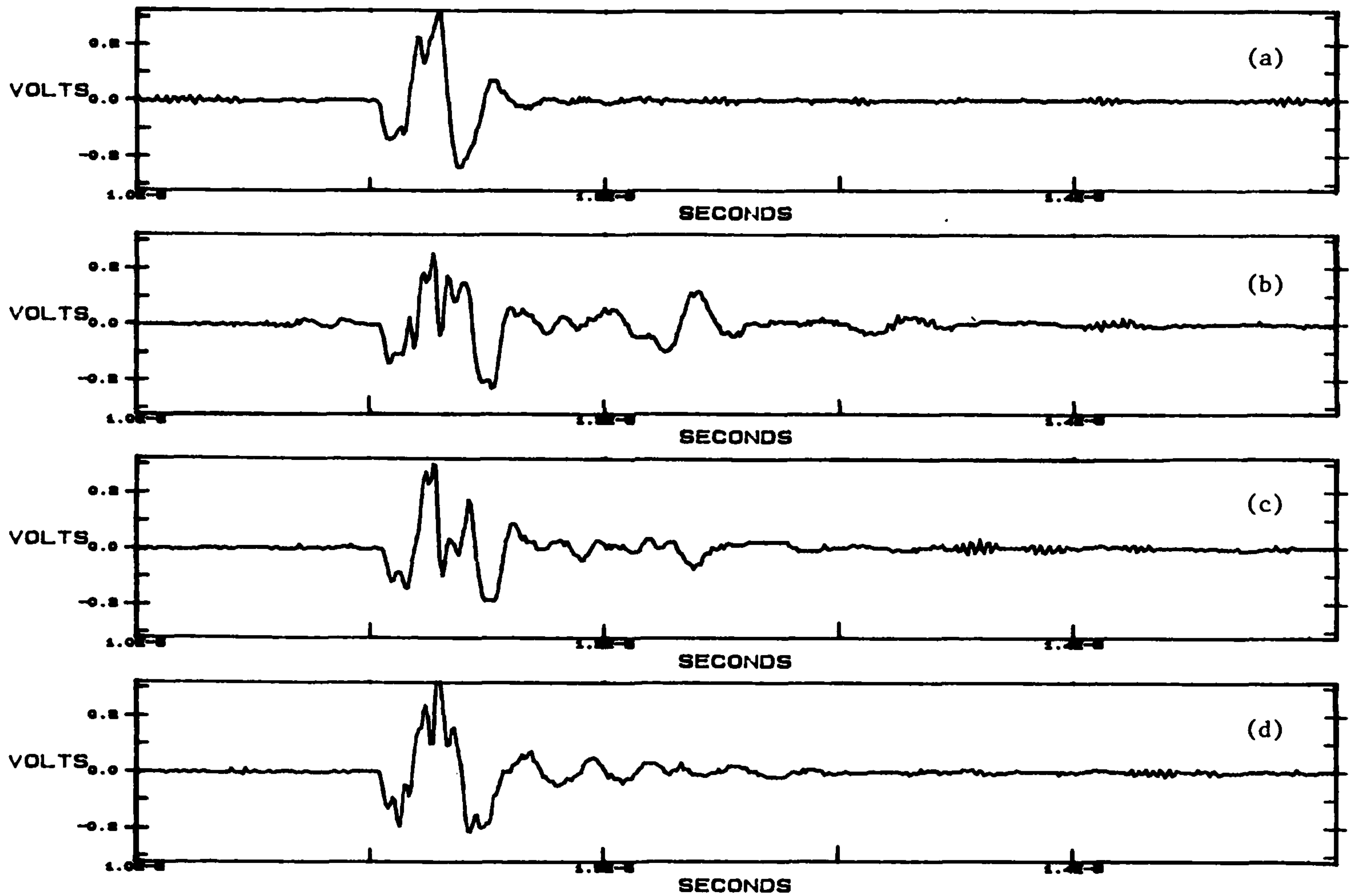

Figure 12. A-scans for water immersion method, 15 MHz/0.25"; a) transducer response, b) specimen ID S335, c) specimen ID S3319, d) specimen ID S3329.

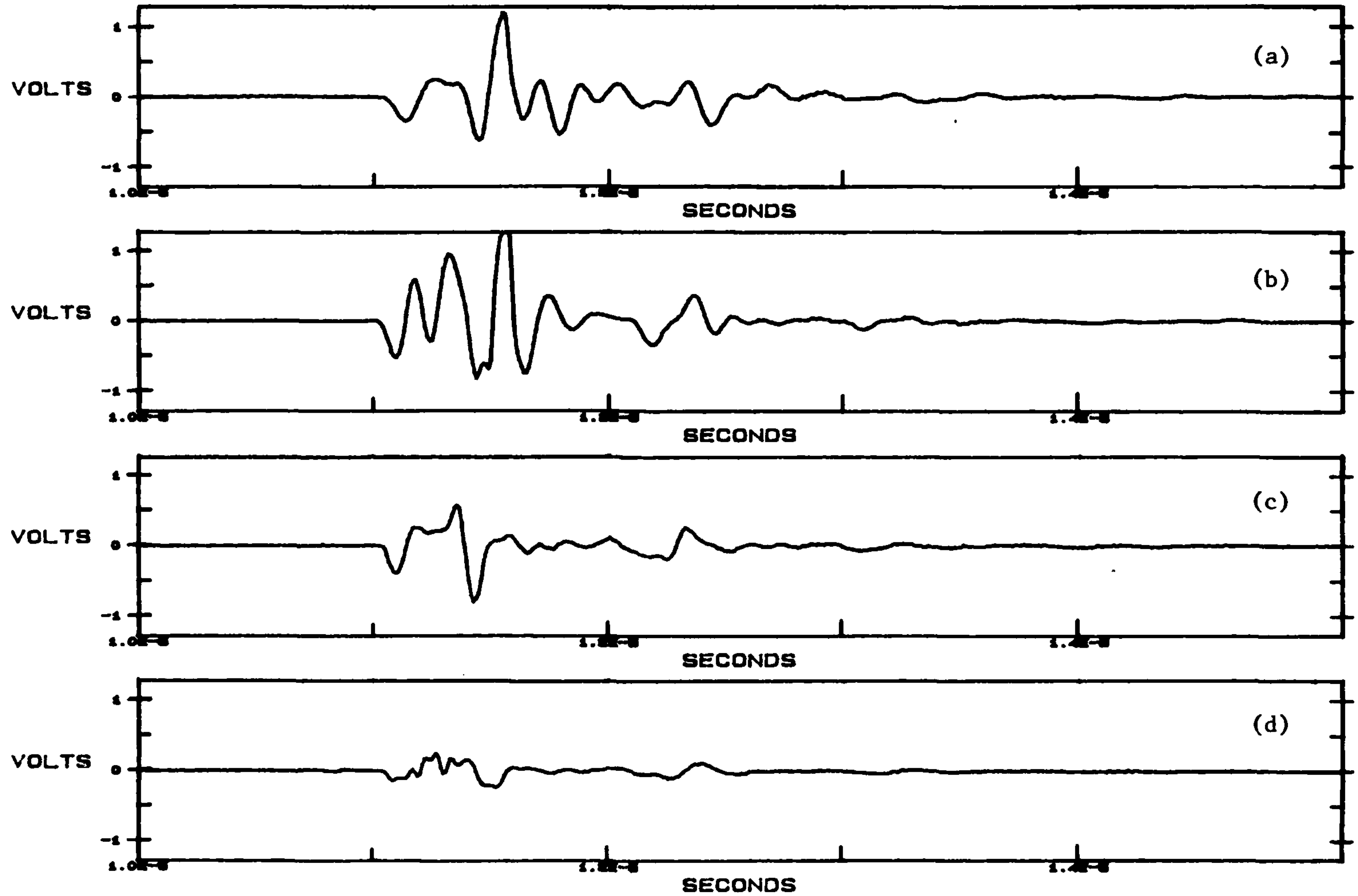

Figure 13. A-scans of specimen ID S335 versus transducer frequency using water immersion method; a) 5 MHz/0.5", b) 5 MHz/0.25", c) 10 MHz/0.25", and d) 15 MHz/0.25".

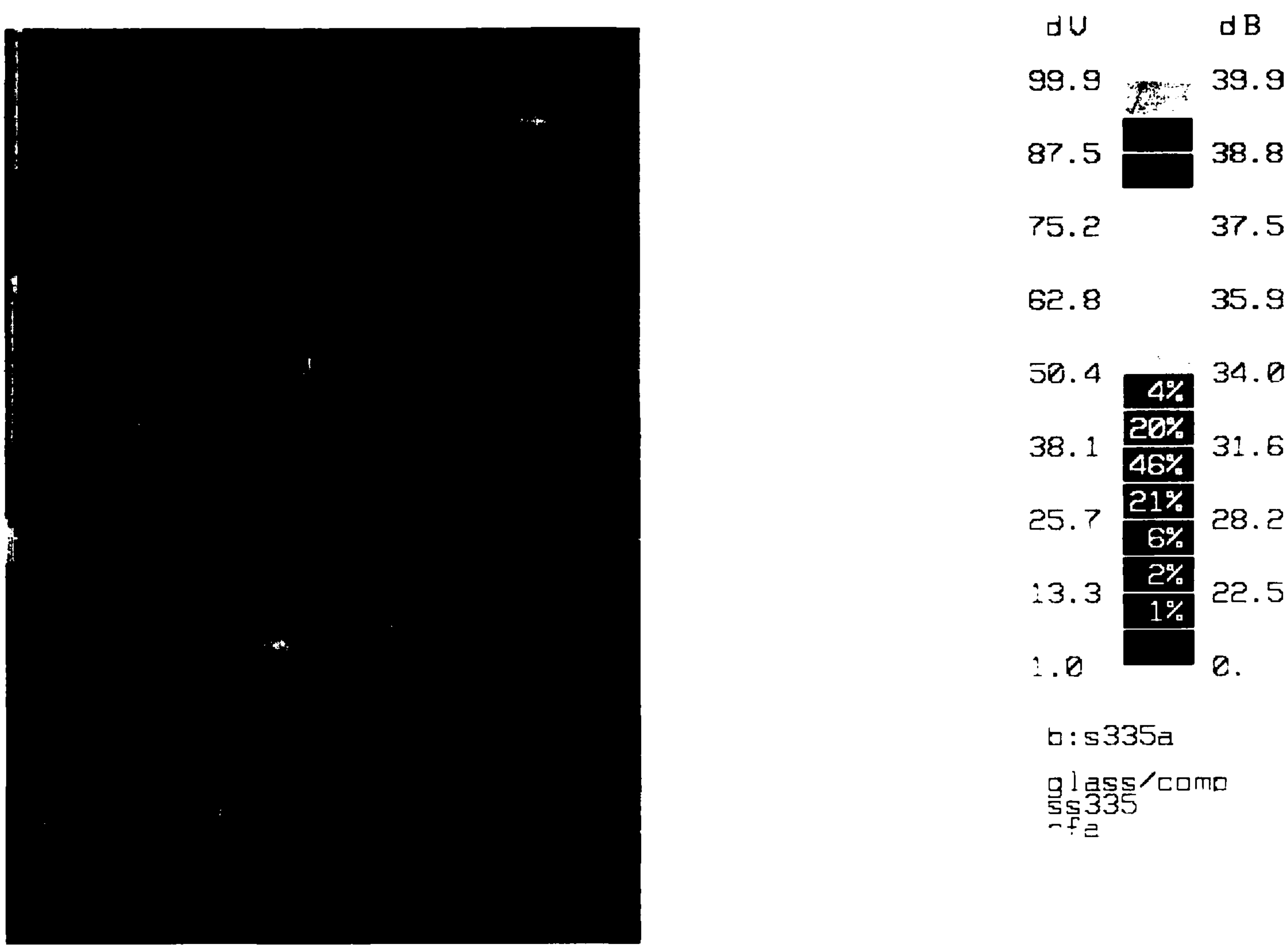

Figure 14. Attenuation C-scans of specimen ID S335.

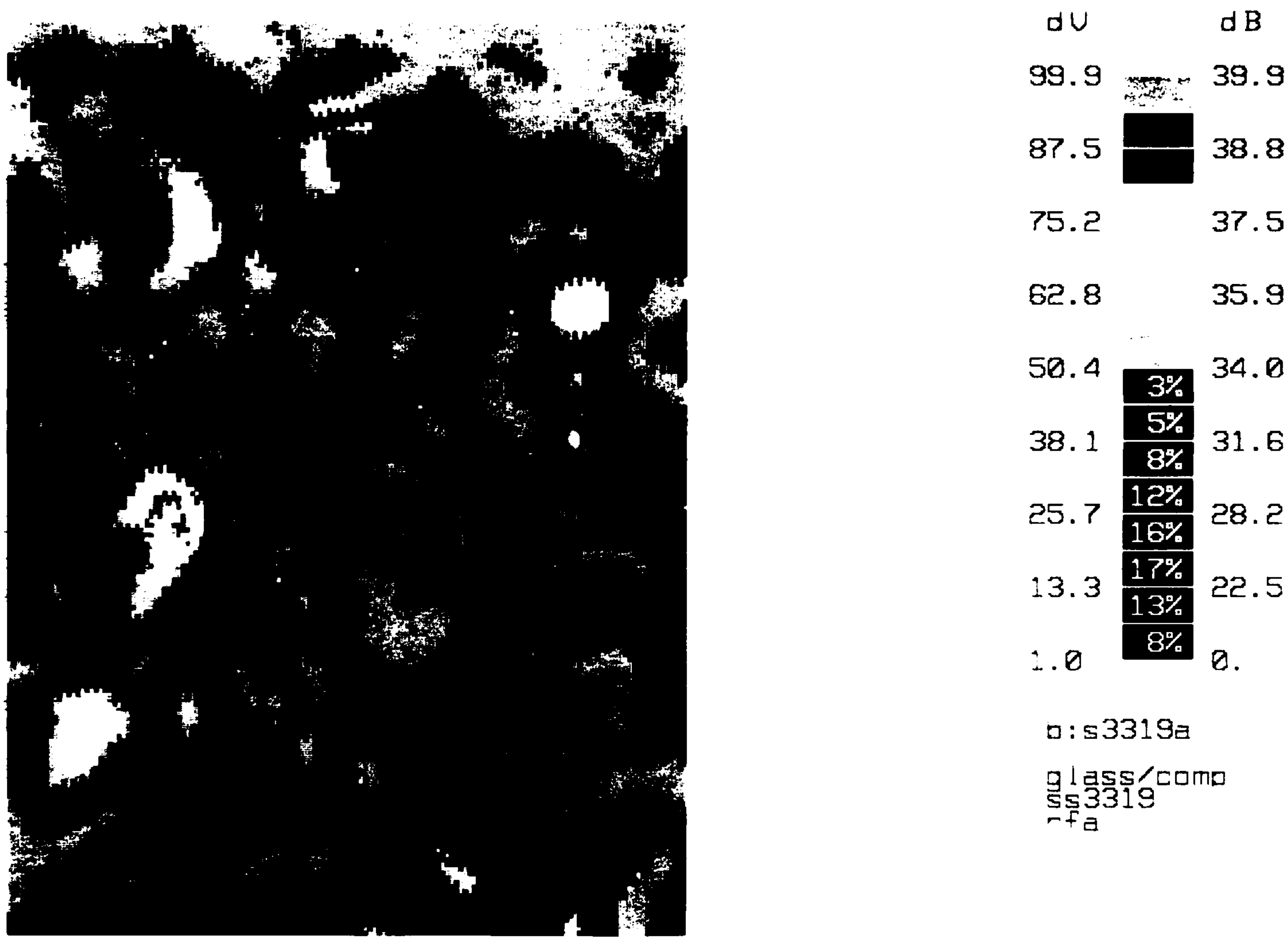

Figure 15. Attenuation C-scans of specimen ID S3319.

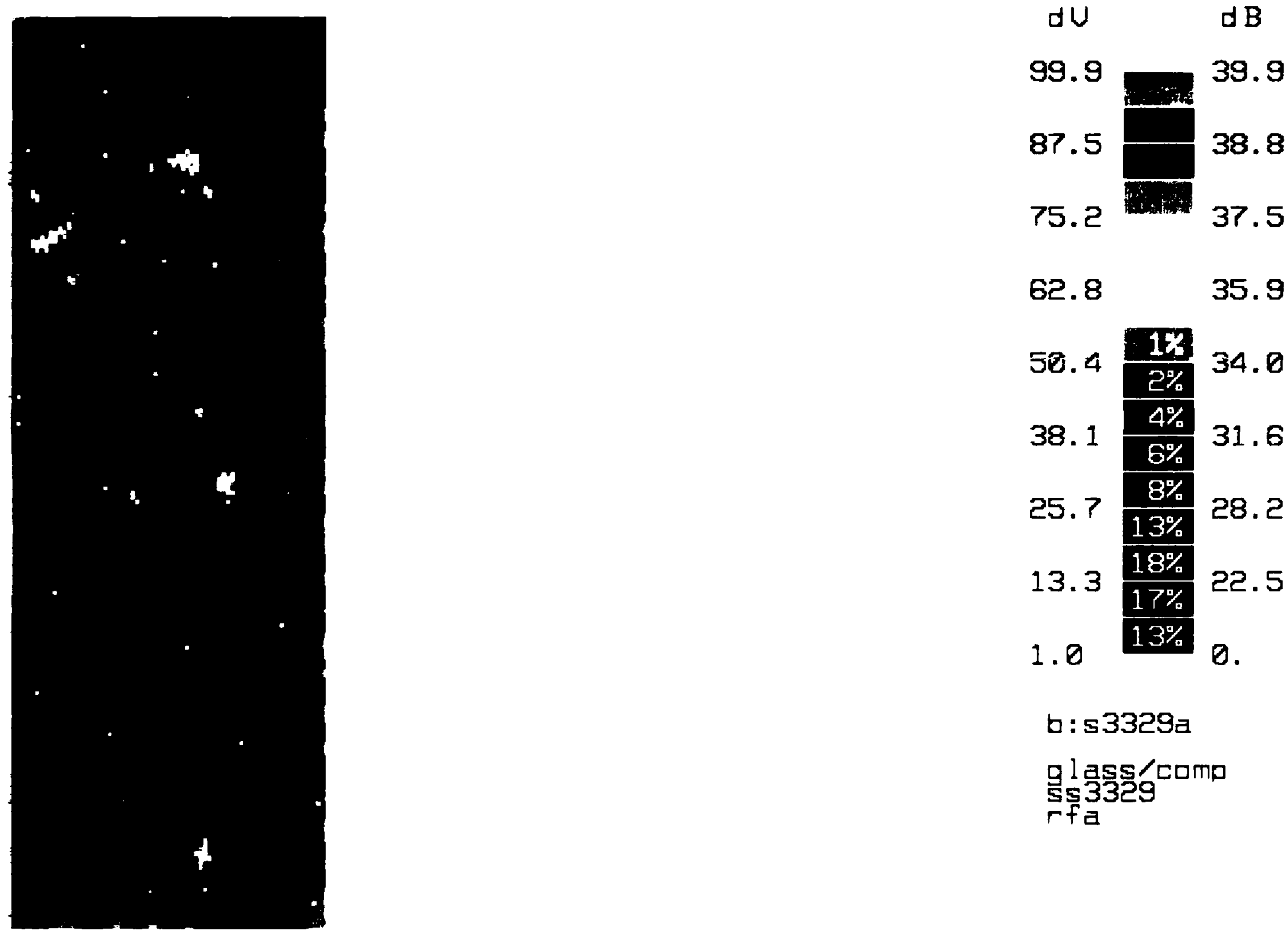

Figure 16. Attenuation C-scans of specimen ID S3329.

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